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ANALYSIS OF CONTRUCTION DESIGN ESTIMATION
PRACTICES OF PUBLIC WORKS CENTER,
GREAT LAKES

by

Stephen L. George

March 1987

Thesis Advisor: James Fremgen

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Computer Aided Design and Drafting System, with greater savings projected when the system is fully installed.

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Analysis of Construction Design Estimation Practices at Public Works Center, Great Lakes

by

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requirements for the degree of

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ABSTRACT

The purpose of this study was to develop a statistically validated predictive model for construction design man-hours to aid in the decision-making process for assigning projects to PWC engineers and Architect-Engineer firms. This study was performed at PWC, Great Lakes and consisted of personnel interviews and the compilation of a database from internal reports. Although a predictive model was not developed, it was discovered that the design man-hours estimation procedure is inaccurate and causes PWC to hold customer funds that could be used for other purposes. A decision-making model was developed to assist in assigning projects to in-house design resources or to Architect-Engineer firms. In addition, significant cost savings are already being realized through the use of the Computer Aided Design and Drafting System, with greater savings projected when the system is fully installed.

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I. INTRODUCTION

A. PROBLEM STATEMENT

In Fiscal Year 1983 Northern Division, Naval Facilities Engineering Command delegated the Special Projects program for 13 mid-western states to Public Works Center, Great Lakes. The resultant increase in design workload severely taxed the Center's design staff. Increases in manning level were authorized but were not sufficient to handle the workload. Increased emphasis was placed upon contracting design with Architect-Engineer firms. the primary concern was whether it was more cost effective to contract project design or to retain it in-house. As the amount of work in the backlog increased, the concern changed to what the proper mix of Architect-Engineer design and in-house design should be. The Naval Facilities Engineering Command goal was set at 20% in-house design and 80% Architect-Engineer design. Local Public Works Center design managers attempted to achieve this goal but very quickly realized the difficulty in attaining the goal and maintaining a viable design staff. There was a need to develop a set of decision-making criteria or a statistical model that would aid in determining which design resource to use for each project. In addition, the Public Works Center aware of declining productivity in the face of the increasing workload. This decline was adversely affecting not only

relationships with customers but the cost of doing business, by increasing the unit cost of performing design.

B. OBJECTIVES OF RESEARCH

The original objective of this thesis research was to develop a statistically validated decision-making model for use in determining whether to retain design in-house or to contract it to an Architect-Engineer firm. In addition, an objective analysis of the organization and management of the design division should yield recommendations that will improve productivity and favorable affect the unit cost of performing design.

Analysis of internal reports, records, and design practices for construction design, with emphasis on the decision process, accompanied by a well-structured database should achieve the following objectives:

1. Provide the development of a decision-making model for deciding which design resource to use.
2. Provide recommendations to improve productivity in the construction design process.
3. Provide examples of possible cost savings to be obtained by the implementation of a decision-making model and productivity improvements.

C. METHODOLOGY

The research was conducted in three phases. The first phase was a review of pertinent literature and data collection. The literature search was conducted at the

Naval Postgraduate School library and the Defense Logistics Studies Information Exchange for theses, papers, articles or other publications that might have a bearing on this study. The collection of data took place in September 1986 at Public Works Center, Great Lakes, Illinois and included data from FY83 through FY86.

The second phase included performing numerous analytical computations to determine the feasibility of developing a statistical model to aid in design man-hour data were used to predict actual design man-hours in an effort to develop a predictive model. It was at this point that the discovery of extremely inaccurate design estimates was made. in analyzing the effect, it was determined that design man-hours estimates alone could not predict actual design man-hours. To develop a model to accurately predict (or estimate) design man-hours might require more data than were available. Some of the desired information was simply not recorded in any internal or external reports. Other information could not be accurately and consistently extracted from the data sources available. Even with additional data, however, it is possible that no reliable predictive model could be derived from past experience.

The third phase of research was the analysis of management and design practices in Production Engineering and Production Scheduling. Through interviews with PWC

personnel at several levels of the organization, a picture of the decision-making process was developed. Comparisons were made with the Public Works Operations Manual [Ref. 1], good management practice (as generally described in the literature), and the actual practices employed at PWC, Great Lakes.

D. THESIS ORGANIZATION

Chapter II provides a background discussion of the purpose and function of the Public Works Center, specifically PWC, Great Lakes. The sources of work and flow of work pertaining to design is discussed and diagrammed. Finally, the critical points in the decision-making process are explained.

Chapter III is a brief explanation of cost and its components. Cost analysis is defined from the perspective of the customer and the Public Works Center.

Chapter IV describes the methodology of the thesis research. Included are the development of the database, the analytical computations, the explanation of regression analysis, and an explanation the failure of model formulation.

Chapter V is an examination of the computations and regression analysis in the previous chapter. Included are the findings from the analysis of management and design

practices. Where applicable, findings are related to cost both to the customer and to PWC.

Chapter VI concludes the thesis with a summary of the background discussion, the major findings of the study, recommendations for improvement, and areas for future research.

E. SUMMARY OF RESULTS

Increases in design staff of PWC, Great Lakes have been only partially successful in meeting the heavy design requirements. Reliance upon A-E design has increased but has presented its own difficulties. There are several areas that need improvements. First, estimating design man-hours requires improvement. No predictive model was developed to estimate design man-hours. Second, project scheduling procedures need to be standardized. Third, the internal reorganization or Production Engineering needs to be monitored to insure that it has the desired effect of increasing productivity. finally, the CADD system appears to be meeting the projections for cost savings. PWC needs to expedite the installation and implementation of this system, as it portends significant improvements in productivity and design quality.

II. BACKGROUND

A. PUBLIC WORKS CENTERS

In general, Public Works Centers (PWC's) were developed in order to provide facility maintenance and repair services to large groups of Navy shore activities in widely scattered geographical locations. PWC's are responsible for the maintenance, repair, renovation, and demolition of Navy and Marine Corps real property and utilities within their geographical jurisdiction. Seven PWC's worldwide serve the entire Navy shore establishment. In order to perform their function, PWC's are outfitted with intrinsic construction design forces. The major purpose of these design forces is to provide the Navy with in-house professional engineers to develop plans and specifications for the maintenance and repair of real property and to provide professional review of designs accomplished by architect-engineer (A-E) firms. These design forces are intended to provide rapid, cost-effective design for PWC shop forces and civilian contractors as the need arises. All PWC's operate within the Navy Industrial Fund. The Navy Industrial Fund allows the PWC to charge the customer command for work performed for that specific activity. There are also specific areas of work that must be funded by the Naval Facilities Engineering Command (NAVFACENGCOM) itself. NAVFACENGCOM is

the sponsor of the PWC's, through six Engineering Field Divisions located throughout the United States. Because of these funding requirements, the need for attention to costs is particularly important. Design costs are a major portion of a PWC's budget. Since one of their major products is design and since these costs can be controlled, design costs become extremely important to the successful operation of a PWC.

B. PWC, GREAT LAKES

PWC, Great Lakes is the Public Works Center serving the northeast quadrant of the United States, falling under the supervision of Northern Division, Naval Facilities Engineering Command (NORTHDIV). Until Fiscal Year (FY) 1983 PWC, Great Lakes had as its main responsibility the minor maintenance and repair of buildings and facilities within its geographical area. Most work was done by PWC shop forces in local areas and by contract in remote areas. The limitation of local authority to do maintenance and minor repair was $25,000 per project for normal maintenance and $75,000 for minor repair. Any project outside these limits required prior approval by Northern Division, Naval Facilities Engineering Command. Prior to FY 1983, NORTHDIV had the responsibility for Special Projects (maintenance greater than $25,000; repair greater than $75,000), Minor Construction, and Military Construction (MILCON). Because of the

increasing workload and lack of timely response, NORTHDIV delegated the Special Project program to PWC, Great Lakes. [Ref. 2]

The advantage to the customers was to be threefold. First, PWC, Great Lakes was in closer geographic proximity to the majority of work required. NORTHDIV is located in Philadelphia. Second, there is a greater availability of A-E firms in the Chicago area than in Philadelphia for those projects requiring design by professionals outside the PWC. Finally, it was believed that local control of the Special Project Program would expedite services all the way from design to completion. The advantages to the PWC were greater control over its own work schedule and the capability for more effective planning of maintenance and repair work needing to be done. [Ref. 1]

C. PRODUCTION ENGINEERING

Located in the PWC organization is the Production Engineering Division, Code 420 (see Figure 1). The function of this group is to prepare technical documents for maintenance and repair of facilities. The technical documents include plans and specifications for the following types of work:

- Repair
- Maintenance
- Alterations

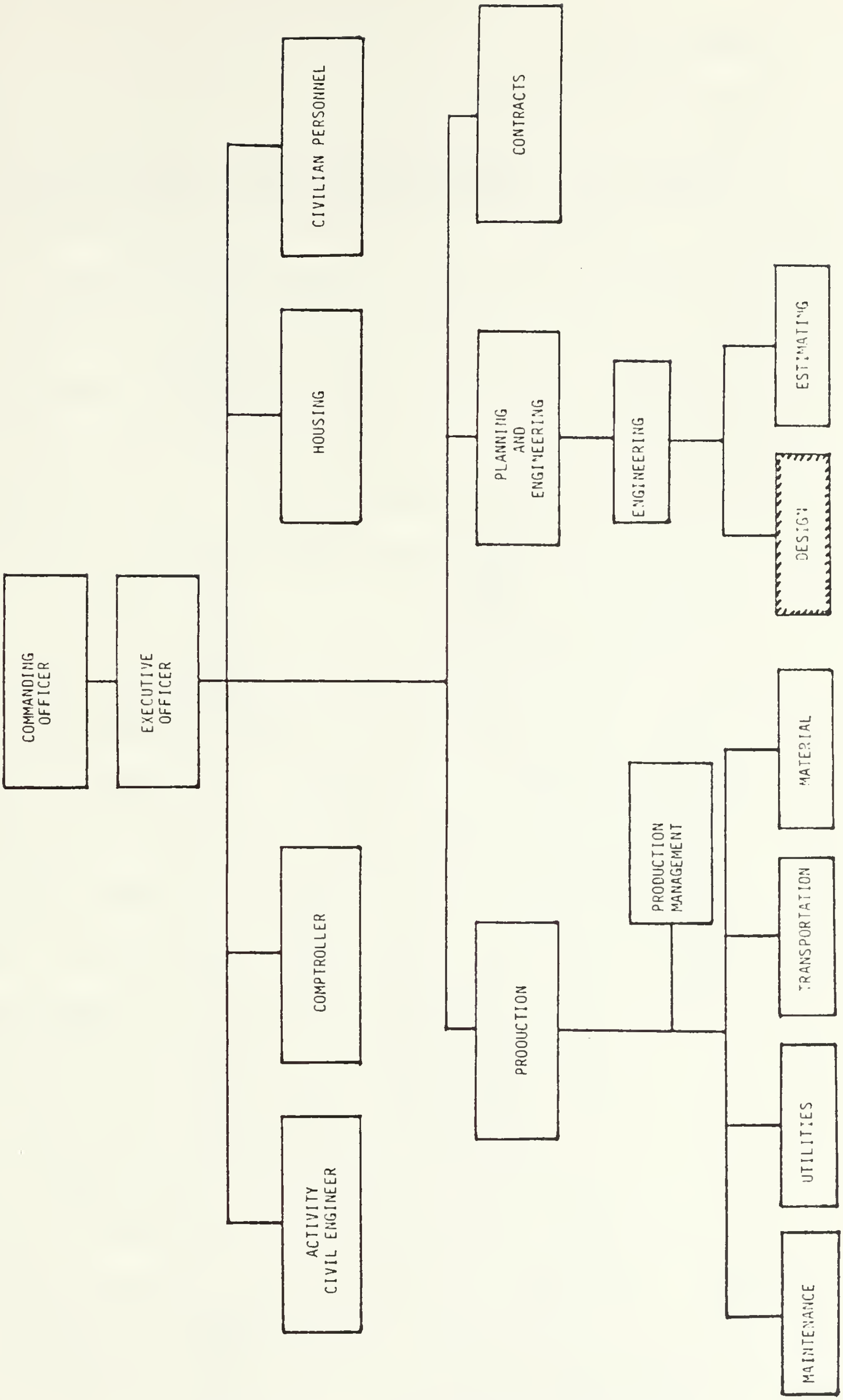

Figure 1. PWC Organization

- Construction
- Engineering studies
- Technical portions of maintenance service contracts

In order to accomplish this work, the Production Engineering Division carries an array of engineering skills, including architects, civil engineers, electrical engineers, mechanical engineers, draftsmen, and engineering technicians. In addition, the division includes support staff such as secretarial skills, specification writers, and a librarian. Figure 2 shows the organizational structure of Code 420 at PWC, Great Lakes. [Ref. 1]

Although the majority of the delegation of work from NORTHDIV did not occur until FY 1983, two Special Project plans were reassigned in FY 1982. In FY 1983 the major portion of Special Project work was delegated to PWC, Great Lakes. During this time the number of design personnel in Code 420 increased very little and very slowly. While some of the Special Project work was done by in-house design forces, it became necessary to rely upon A-E firms to an increasing extent. Appendix A gives an historical breakdown of total manhours, total dollars, and percentage of total workload assigned to in-house and A-E design forces. NORTHDIV's informally stated goal for desired percentages of work between in-house and A-E firms in 20% and 80% respectively [Ref. 3].

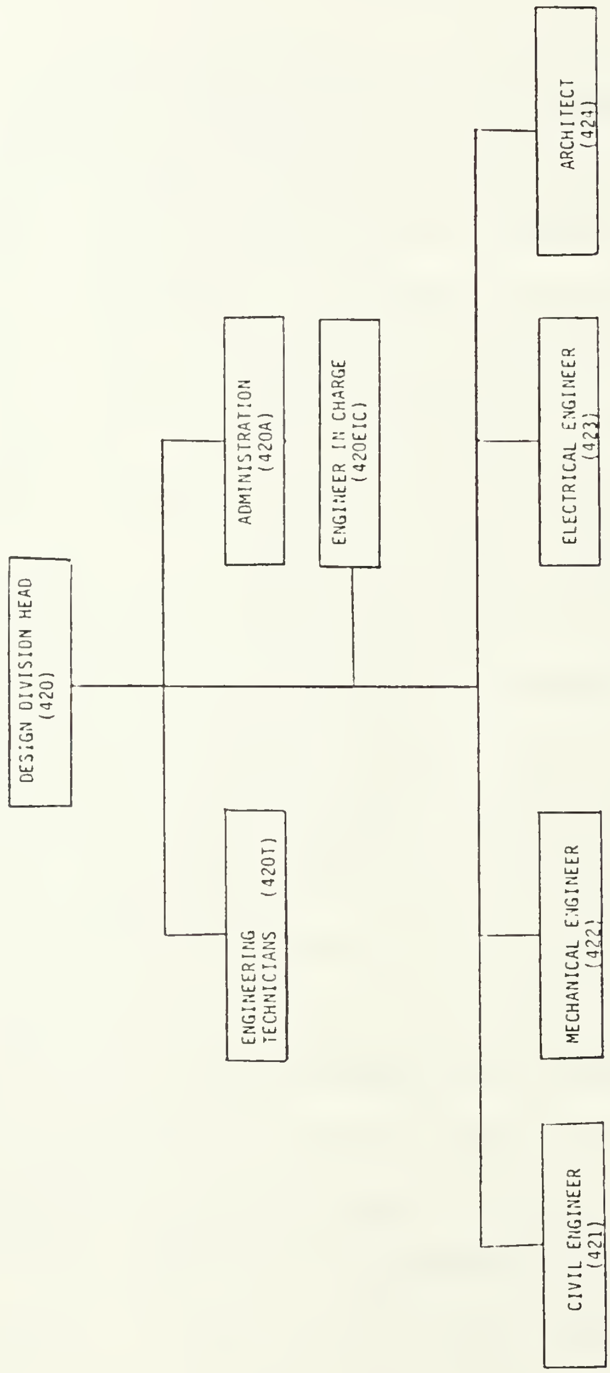

Figure 2. Organization Structure Code 420
PWC, Great Lakes

With the delegation of the Special Projects program from NORTHDIV came the challenge of actually increasing services by providing engineering services in a lesser amount of time. Initially, Production Engineering set a goal of 180 days average completion time from receipt from the customer to completion of final plans and specifications prior to contracting (or scheduling by PWC shop forces). The additional challenge presented by the offload was to develop an estimate of what it cost to accomplish a design. At this point the first emphasis on controlling design cost arose. However, due to the volume of work, nothing was done. Although Code 420 staff grew from FY 1983 to FY 1985, it became clear that, because of the increased restrictions on hiring practices in the Federal sector, expanding the engineering staff to the desired level would be impossible, Nevertheless, the workload for the design division kept increasing. As workload increased, the backlog of work awaiting design increased, thus increasing the amount of time taken to produce designs and contracts. This time delay resulted in greater costs as inflation affected construction costs. In addition, the lack of staff increased the pressure to perform and lead to a tendency to produce hasty designs requiring extensive rework, thus increasing the cost of design. Out of this environment was born the need to look at and control the cost of design.

D. WORK FLOW

1. Types of Work.

There are four basic types of work the PWC engages in.

a. Specific Work.

This work entails major repair, replacement, and renovation of plant property facilities. it generally requires more than 80 hours of effort by PWC shop forces, and may be accomplished by PWC ship forces or contractors.

b. Minor Work.

This work consists of minor construction, alterations, maintenance, and repair of plant property facilities. this work requires more than 16 and less than 80 man-hours for completion, and may be accomplished by PWC ship forces or contracts. When contractors perform work of this nature, it is generally because the work requires skills not available to PWC forces.

c. Recurring Work.

This is maintenance work of a recurring nature and has no specific, man-hour guidelines. This work is basically preventive and corrective maintenance on existing facilities and utilities. It is generally accomplished by PWC ship forces. When it is accomplished by contractors, the work is performed under a maintenance service contract.

d. Emergency/Service Work.

This type of work encompasses any situation requiring immediate attention (such as a ruptured water pipe or clogged toilet). Normally these situations require less than 16 man-hours to correct. This work is performed entirely by PWC ship forces unless there is an emergency service clause written into a maintenance service contract.

2. Sources of Work.

There are basically only two sources of work (although there is in a sense, a third source for high cost Special Projects).

a. Customers.

Tenant activities (all activities within the geographical area served by PWC, Great Lakes) request work to be done by PWC. They submit work request for specific and minor work which may or may not ultimately be accomplished by PWC work forces. Any design requirements may also be performed by either in-house engineers or A-E firms. Work exceeding the man-hour limit for specific work or the dollar limitations for repair and maintenance is then submitted as a special project.

b. Public Works.

Because PWC is charged with the maintenance and repair of all real property, work is generated through normal inspection of facilities and through long-range planning of repair, replacement, demolition, and new

construction. Work may be specific, minor, or of such scope as to require a special project, minor military construction, or MILCON (the distinctions between these categories is based upon the dollar value of the cost estimate). Most of the minor work is scheduled for PWC ship forces to accomplish, while large projects are contracted out. Design, however, may be accomplished by either in-house staff or A-E firms.

c. Special Projects.

Whenever work requested exceeds $25,000 for maintenance and $75,000 for repair/alteration, it must be submitted as a Special Project. Special Projects are basically specific work that exceeds local PWC authority to approve. The maximum limit for Special Project work is $200,000. It is this portion of the workload that NORTHDIV delegated to PWC, Great Lakes in 1982. Work on these projects is performed almost exclusively by contractors. However, design may be accomplished either in-house or by A-E's. By FY 1984 the offload of Special Project work had reached 122 projects totaling nearly $20 million in construction work [Ref. 2].

3. <u>Flow of Work</u>.

The basic flow of work through the PWC organization is shown in Figure 3. The requirement for work is generated by PWC and customer activities and is delivered to PWC in

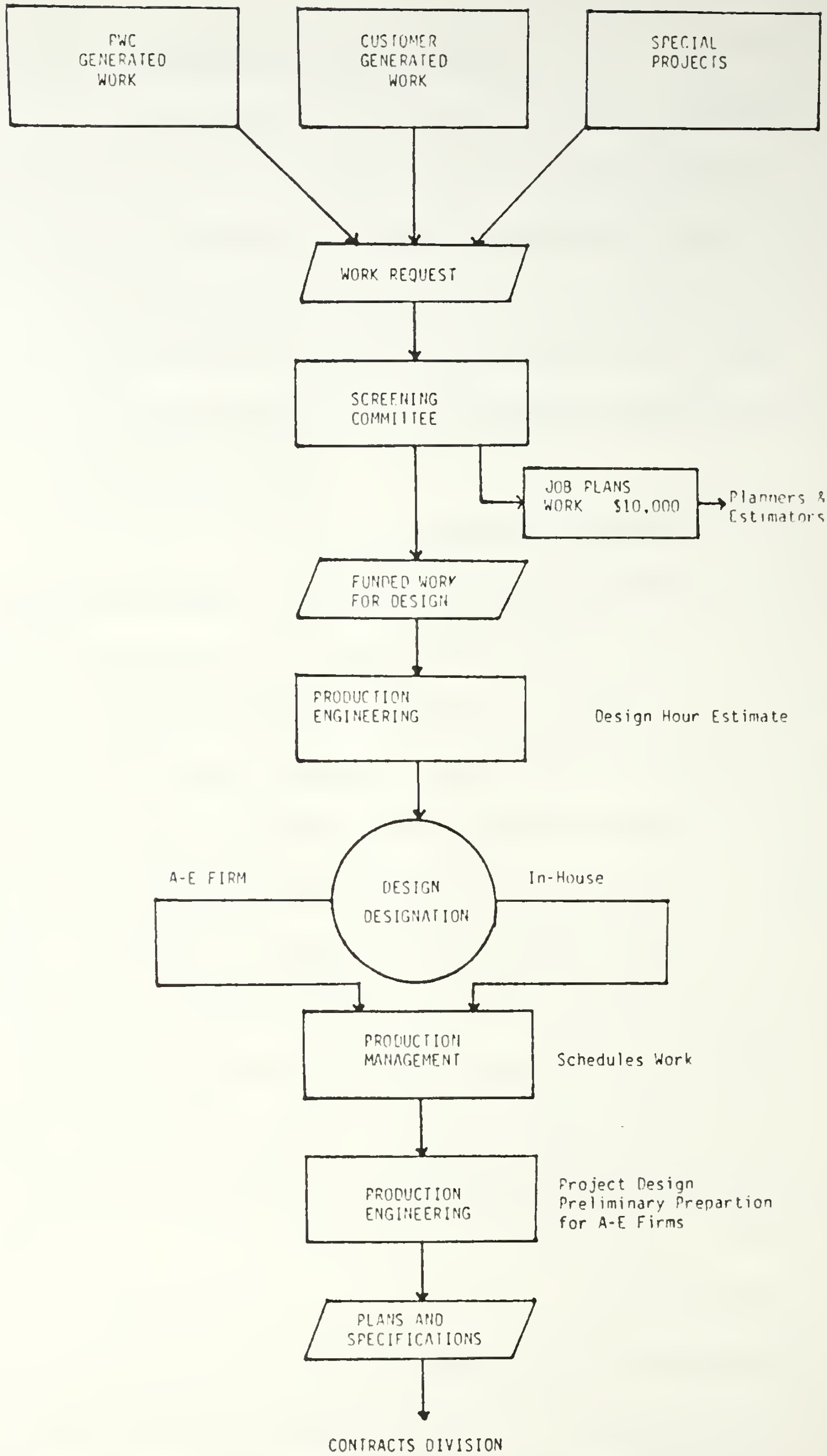

Figure 3. Flow of Work

the form of a work request. Each work request is logged in as to date received, type of work, date desired by the customer, and estimated cost. All work requests received during a particular week are screened by a screening committee. This committee is made up of representatives from the Production Management (Code 350), Production Engineering (Code 420), and Planning (Code 100) Divisions. Their purpose is to screen the work requests for assignment. The first assignment made is whether the work request will be designed by in-house staff or by an A-E firm. The second assignment is whether the actual work will be performed by PWC shop forces or civilian contractors. Once assigned, work requests designated to be designed by either in-house or A-E firms are forwarded to Production Engineering. At this point the division head of Production Engineering evaluates the work request with respect to the skills and manpower available to him and makes a final recommendation as to in-house or A-E design. The Engineer-in-Charge (EIC) then estimates the number of manhours required to develop the necessary design for plans and specifications. Once this estimate in completed, the work request is sent to the customer for funding of the design. When the work request is resubmitted, it is screened again by the screening committee to evaluate the need for any changes in assignment. The work request is then sent to the Production

Management division to await scheduling. Once scheduled, the work request (now a job order) is forwarded to Production Engineering (Code 420) for either actual design or preparation of documents to allow an A-E to do design. Once design is completed and approved by Production Engineering, the plans and specifications are given either to the Contracts Division or to PWC ship schedulers for the actual accomplishment of the work. [Ref. 4]

E. DECISION POINTS AND VARIABLES

1. Screening Committee.

As mentioned above, this committee meets weekly to determine the basic disposition of work requests submitted or resubmitted to PWC for action. This committee consists of the following representatives:

a. Production Department Head, Code 30

b. Planning/Engineering Department Head, Code 400

c. Production Management Representative, Code 350

d. Senior Activity Civil Engineer, Code 110

e. Production Engineering Representative, Code 420

f. Planning/Estimating Representative, Code 430

g. Contract Department Representative, Code 90

Each work request is evaluated with respect to priority, current working (cost) estimate (CWE), current workload, current backlog, manpower availability projections, and in-house capability.

The work request is first evaluated by the dollar value of the current working estimate (CWE). This will provide an initial indication of who will perform the work. Large dollar value projects (those greater than $25,000) are generally reserved for accomplishment by contractors. Projects beneath the $25,000 ceiling are evaluated further in deciding who should perform the work. The decision on who performs the design is based upon the perceived capability of PWC to handle the design and the availability of A-E firms to do the design. As a general rule, extremely large projects are reserved for the A-E firms, while extremely small projects are given to PWC design forces. There is no apparent dollar volume that truly defines extremely large. Under $10,000 is generally accepted to define extremely small dollar value. In cases where work falls into the Special Project category, the work request is returned to the customer for preparation of the proper paperwork.

The work request is then evaluated according to priority. There are basically five levels of priority (see Figure 4). Customers request a priority based upon their time requirements and the importance of the project to their activity. The Screening Committee evaluates that priority on the basis of PWC plans, availability of manpower, and whether the customer has made funds available. It is their

GREEN LIGHT: The highest priority available; assigned only by the Commandant, Naval Training Center (flag rank); this work is of such immediate nature that it requires rescheduling all other work necessary to accomplish it in a timely manner. [Ref. 5]

PRIORITY 1: The highest priority assigned by PWS; this work is of an urgent nature and requires attention as quickly as possible without disrupting the current schedule. The serious nature of work dictates little delay in accomplishment.

PRIORITY 2: This work is of an important nature but does not have the urgency to displace other work in the schedule. This is generally the highest priority assigned to customer work requests.

PRIORITY 3: This priority is assigned to specific and minor work of the nature of alteration or renovation; there is little sense of urgency; the work will be accomplished as openings appear in the work schedule.

PRIORITY 4: This work can be deferred without major problems or to work that will be funded at a later date. This work will be accomplished when there is not other work of higher priority available. There is no urgency in this work. Generally this is discretionary work.

Figure 4. Levels of Priority

option to upgrade, downgrade, or allow the customer's priority to stand.

Once the prior two evaluations have been made, the Production Scheduler evaluates the work request with respect to the current backlog both in Production Engineering and the PWC shops to se if there might be a lengthy delay in either design or accomplishment of work. The current manpower availability projections are also considered. An initial recommendation is made for in-house or outside accomplishment and for in-house or A-E design.

At this point, the Production Engineering representative will evaluate the work request as to its technical requirements and the availability of the necessary skills to design the project in-house. Projects initially recommended for either in-house or A-E design may be reversed at this point on the basis of Code 420's perception of conditions within his division that affect his capability to accomplish design work. Once all variables have been evaluated, the committee arrives at a consensus concerning the initial disposition of each work request. Work requests not requiring engineering are forwarded to the Planning/ Estimating Divisions; work requests requiring engineering or fundable estimates are forwarded to Production Engineering for action.

2. Production Engineering Division Head.

The Division Head receives work requests requiring action from the screening committee. He forwards the work request to the EIC whose job it is to estimate the number of manhours it will take to design the project. Once he has completed his estimate, he returns the work request to the division head who then makes the final decision regarding in-house or A-E design. He takes into account the following factors.

a. Size of Job.

The size of the job in terms of dollars and estimated manhours to accomplish the design is evaluated with respect to current backlog and manpower availability. In addition, the Division Head evaluates the size of the job with respect to an A-E firm's ability to do business with the government profitably. Small jobs for small dollar values are very difficult to make a profit on. The EIC may also recommend that small jobs or jobs of like design requirements be combined.

b. Complexity of Job.

The complexity of the job may require special design skills not available to PWC. Conversely, certain jobs may require historical information or understanding of special conditions that would require in-house design.

c. Current Skill Inventory.

If there are staff engineers with the resident skills and experience to design the project and other factors are consistent, the design will be accomplished in-house. Specialty skill requirements will almost always result in an A-E firm doing the design.

d. Training Requirements.

Certain jobs may be perfect for A-E design, but PWC has a responsibility to provide training and experience for younger engineers and engineering technicians. So, some jobs will be designed in-house to meet this need.

e. Current Backlog.

The Division Head evaluates the current backlog based upon engineering discipline (as opposed to strictly man-hours as done by Production Management). This may dictate a change in which design resources are used.

f. NAVFAC Goals.

As stated previously, the goal is to only do 20% of the total design work by in-house forces, leaving 80% to be done by A-E firms. The Division Head will evaluate each work request based upon his perception of the current percentage of work assigned to each resource.

g. Current A-E Load.

The Division Head must also take into account what A-E skills are available and how much workload they

have been assigned thus far in the fiscal year. Since most A-E design is done on "open end" contracts (where a certain dollar volume of work is promised and work is assigned by work order), the Division Head must balance the workload of all A-E firms under contract and be sensitive to their other business requirements.

Once the Division Head has taken into account all the above factors, he must make his final decision based upon his evaluation of overall capability to do the design in a timely fashion. The Division Head is hampered by the fact that design manhour estimating is an inexact science at best. Also, there are times when the evaluation criteria conflict and his recommendation becomes a "best guess" as to what should be done. In addition, the Division Head is faced with customers desiring input into his decision by asking for a particular resource be used, despite the professional evaluation of the other factors. Upon the assignment of the design as to in-house or A-E, the Division Head forwards the work request to Production Management for scheduling. [Ref. 6]

3. Production Manager.

The production manager dealing with engineering design has only one basic concern - scheduling work by manhours for the Production Engineering division. In general, whatever the EIC has decided upon concerning the

design forces to be used is agreed to by the scheduler. Both in-house designs and A-E designs require work by Production Engineering. In-house projects require preparation of plans and specification, while A-E design projects require the preparation of technical documents prior to release to an A-E firm. When the backlog is larger than normal, the scheduler will recommend a reevaluation of all work requests in the backlog by the screening committee in order that more work requests be sent to A-E firms for design.

III. COST

A. INTRODUCTION

The main emphasis of this treatise is control of design man-hours within the Production Engineering Division of PWC, Great Lakes. The importance of man-hour management is cited below:

> It seems apparent that design time is an important civil engineering resource that must be allocated as efficiently and effectively as possible. In a period of increasingly austere manning and budgets, design time is a scarce resource that demands positive management and control. [Ref. 7]

There are two aspects of cost that must be dealt with. First, cost can be defined as cost to the customer. In this case cost is driven by the number of man-hours expended in performing design. Second, cost can be defined as the expense of operating the PWC. In each case, the significance of controlling design time is slightly different. From the "cost to customer" viewpoint, the fewer design hours expended, the lower the cost of the project. From the "PWC operating cost" perspective, efficient use of design man-hours lowers the cost per work request of design services, thereby decreasing cost to PWC. PWC's motivation for managing cost is accountability to both customers and NAVFACENGCOM.

B. EXPLANATION OF COST

Once a project has been accepted by PWC and a man-hour estimate for design has been made, the customer must provide funds to pay for project design. The connection between man-hours and customer funds is the billing rate. The billing rate is multiplied by the estimated man-hours to reflect the payment due from the customer. The billing rate reflects PWC's cost of doing business. It consists of a standard hourly rate, an acceleration rate, and an applied overhead rate. In cases where overtime is used, a premium rate is added to the normal billing rate in order to calculate the overtime rate.

The standard hourly rate reflects the weighted average cost of engineers, engineering technicians, draftsmen, and secretaries in the production Engineering division. Both productive and non-productive personnel are included in this rate. Throughout PWC each productive division has its own separate billing rate, so all non-productive personnel are charged to their respective departments as opposed to being included in applied overhead. [Ref. 8]

The acceleration rate simply consists of fringe benefits for the personnel in the Production Engineering division. Specifically, these benefits include Social Security, annual leave, sick leave, insurance, and retirement benefit costs. [Ref. 8]

The overhead cost consists of an assessment of plant property cost and depreciation cost (both based upon square footage), utility usage, provision for capitalized equipment, provision for inflation, and provision for other economic factors affecting PWC's cash flow. [Ref. 8]

C. COST SAVINGS CONSIDERATIONS

The purpose of addressing cost issues is to identify possible areas of improvement. The results of model formulation and analysis of design management practices of PWC's Production Engineering division may significantly affect the customer's cost of design. In addition, any inefficiencies discovered also affect the productivity and therefore the unit cost of design for PWC. An attempt is made to evaluate the dollar value of savings to the customer where savings in design time can be realized. Not enough information was collected on site to enable the calculation of a unit design cost. Nevertheless, possible areas for productivity improvement are noted for PWC.

All analysis has been conducted using man-hours as the base. Man-hours have the unique distinction of being unaffected by inflation. Applying the billing rate to man-hours gives direct value to the design. Any savings will be immediately recognized. A billing rate of $30 per man-hour has been assumed, as the actual rate is proprietary information of PWC, Great Lakes.

IV. METHODOLOGY

A. DEVELOPING THE DATABASE

1. General

The data for the research were collected at the Public Works Center (PWC), Great Lakes, Illinois. The data were retrieved from various reports and records held within the Production Management Division, the Production Engineering Division, and the Comptroller Division. all within PWC. Although data were collected from FY83 through FY86, only the FY85 data were used in the analysis, as it was the only year that complete records from all three divisions could be matched against one another. Older records in some cases had been destroyed or stored in facilities that were inaccessible. At the time of the study, records for FY86 were not complete and would have been sent too late for inclusion in the analysis.

The data base consisted of 144 work requests from FY85. This does not reflect the entire number of work requests processed in FY85. Rather, 144 was the total number of work requests that were able to be matched through the various internal reports and records kept by PWC. Maintenance service contracts were not included in this number, since little or no actual design work was required and the Technical Specification writer was located in

Production Engineering. The Specification writer also had, as a part of his duties, the drafting of specifications for projects being referred to A-E firms.

2. Components.

Twenty components of data were recorded for each work request from the PWC internal reports. Some of these components are self-explanatory while others require an explanation:

a. Estimated Total Design Man-hours -- This reflects the aggregate of the design man-hour estimate, including supervisory and technical specification writer's time.

b. Estimated Total Design Man-hours without Overhead -- This reflects the aggregate of the design man-hour estimate minus the supervisory and specification writer estimates.

c. Estimated 420A Man-hours -- This is the estimate of administrative man-hours for project design.

d. Estimated 421 Man-hours -- This is the estimate of Civil engineer man-hours required for project design.

e. Estimated 422 Man-hours -- This is the estimate of Mechanical Engineer man-hours required for project design.

f. Estimated 423 Man-hours -- This is the estimate of Electrical Engineer man-hours required for project design.

g. Estimated 424 Man-hours -- This is the estimate of Architectural man-hours required for project design.

h. Estimated 420T Man-hours -- This is the estimate of Engineering Technician man-hours required for project design.

i. Key Code -- This is an internal code reflecting the type of work required by production engineering. Appendix B contains the list of key codes.

j. Estimated Number of Skills -- this reflects the estimated number of different skills required to design a particular project.

k. Actual Number of Skills -- This reflects the actual number of skills required to design the project.

l. Actual Total Man-hours -- This is the actual number of aggregate man-hours the project design took.

m. Actual 420A Man-hours -- This is the actual number of administrative man-hours spend on project design and approval.

n. Actual 421 Man-hours -- This is the actual number of Civil Engineer man-hours spent on project design.

o. Actual 422 Man-hours -- This is the actual number of Mechanical Engineer man-hours spent on project design.

p. Actual 423 Man-hours -- This is the actual number of Electrical Engineer man-hours spent on project design.

q. Actual 424 Man-hours -- This is the actual number of Architectural man-hours spent on project design.

r. Actual 420T Man-hours -- This is the actual number of Engineering Technician man-hours spent on project design.

s. Calendar Days to Complete -- This is the number of calendar days each project took to complete, commencing the first day labor hours were charged to the project and ending the last day labor hours were charged to the project.

t. Work Days to Complete -- This was calculated from the calendar days to complete by using a pre-determined factor (that reflects weekends, holidays, etc.) to arrive at the actual number of work days each project took to complete, commencing with the first day labor was charged to the project and ending the last day labor was charged to the project.

3. Compilation.

The data were compiled using the MINITAB function of the IBM 370 computer at the Naval Postgraduate School. The

data were stored in a two-dimensional array with 20 columns and 144 rows. Appendix B displays the entire database.

B. DESCRIPTION OF THE DATABASE

1. General.

Each of the 20 data elements was collected to enable the analysis of trends, comparisons, and formulation of predictive models. Not all data elements were considered to be relevant to all computations.

2. Descriptive Statistics

Figure 5 reflects various descriptive breakdowns of the database. Total estimated man-hours were broken down into two categories, because not all jobs had estimates for supervisory time required for project design functions. PWC began to include supervisory estimates on all projects in FY86.

In the aggregate, estimated design hours exceed actual design hours by a substantial margin. Several reasons explain the disparity. First, some projects were simply overestimated. Second, some projects were submitted for design and then were canceled prior to completion of design. Finally, several similar jobs were designed simultaneously and caused significant reduction in design time. Information to separate projects by these classes was not readily available at the time of this study.

TOTAL ESTIMATED HOURS

- with supervisory hours.........17,534.0
- without supervisory hours......16,501.0
- actual hours...................11,107.9

PROJECT HOURS BY SKILLS

	Estimated	Actual	Percentage
Administrative	4.0	230.5	2.08
Civil Engineer	3134.0	1899.5	17.10
Mechanical Engineer	5337.0	3530.8	31.79
Electrical Engineer	3483.0	1671.2	15.05
Architectural	4543.0	2470.9	22.24
Technical Support	0.0	1305.0	11.75

DATABASE BY SKILLS/PROJECT

	Estimated	Actual
Single Skills Projects	66.67%	35.42%
Multiple Skills Projects	33.33%	64.58%

DATABASE BY WORK TYPE

	Number	Percentage
PWC Shop	44	30.56
Contractor	21	14.58
Architect/Engineer	19	13.19
Surveys	37	25.69
Preliminary Estimates	8	5.56
Design Review	15	10.42

Figure 5. Total Estimated Hours

The significance of overestimated hours is that they represent customer funds that are provided prior to design. Inaccuracies in estimating design man-hours result in PWC holding customer funds for long periods of time. These extra funds are returned to the customer, but many times they are returned too late to be effectively and efficiently reprogrammed. The significance of underestimated hours is that they represent cost overruns. The customers must provide further funds before design may continue. Once this money is obligated and design charged against it, there is no getting it back. Overruns require immediate reprogramming in most cases. Governmental accounting practices do not permit indiscriminate shifting of funds between over- and underestimated projects.

Figure 6 shows the relative frequency of occurrence of over- and underestimated design time, broken into various classes. Each project was evaluated by comparing estimated total design hours with actual total design hours and determining the percentage difference. If estimated man-hours were greater than actual man-hours, an overestimate occurred; if actual man-hours were greater than estimated, an underestimate had occurred. The calculated percentages were then sorted into the listed ranges to provide an indication of the accuracy of the estimates.

OVERESTIMATED DESIGN HOURS
(number of projects)

	W/Supervisory Hrs	W/O Supervisory Hrs
Hours > 100%	50	43
Hours < 100%	62	58
Hours < 75%	55	49
Hours < 50%	45	43
Hours < 25%	21	31
Hours < 10%	11	10
Hours < 5%	7	7

UNDERESTIMATED DESIGN HOURS

(number of projects)

	W/Supervisory Hrs	W/O Supervisory Hrs
Hours < 100%	32	43
Hours < 75%	32	42
Hours < 50%	27	33
Hours < 25%	16	22
Hours < 10%	8	8
Hours < 5%	3	2

OVER- AND UNDERESTIMATED DESIGN HOURS

(percentage ranges)

	W/Supervisory Hrs	W/O Supervisory Hrs
Hrs > 100%	50	43
+100% < Hrs > -100%	94	101
+75% < Hrs > -75%	85	91
+50% < Hrs > -50%	71	76
+25% < Hrs > -25%	36	53
+10% < Hrs > -10%	18	18
+ 5% < Hrs > - 5%	9	10

Figure 6. DESIGN HOURS

C. ANALYTICAL COMPUTATIONS

1. General

The sample size, means and standard deviations were calculated on 19 of the components in the database to provide basic information concerning the relative dispersion and variability of the information collected. This information is shown in tabular form in Figure 7. Calculations were not performed on the Key Code column, as it is a numerical code signifying the type of work. An analysis of the results for each column was conducted to determine trends, similarities and differences.

2. Total Estimated Hours.

The most significant information contained in these statistics is the difference between total estimated hours (with supervisory hours included) and actual design hours (Row 1 - Row 3). The average difference is 44.7 hours which represents a mean overestimate of 58% of the actual hours.

3. Estimated Hours (without Supervisory hours).

Subtracting out supervisory hours leaves a mean differences between actual and estimated hours of 37.5 hours or 49% (Row 2 - Row 3). The reason for this improvement in accuracy was stated previously as the failure to estimate supervisory hours for all projects.

4. Individual Skill Estimates vs Actual.

The difference between actual and estimated means in all skills (rows 4-15) indicated overestimates, with

	N	MEAN	MEDIAN	STDEV
1. Tot. Est. Hours (w/Supv.)	144	121.80	68.0	239.80
2. Tot. Est. Hours (w/o Supv.)	144	114.60	60.0	235.90
3. Tot. Actual Hours	144	77.10	41.0	131.90
4. Est. Admin Hours	144	0.03	0.0	0.33
5. Act. Admin Hours	144	1.60	0.5	3.68
6. Est. Civil Eng. Hrs.	144	21.76	0.0	45.76
7. Act. Civil Eng. Hrs.	144	13.20	0.0	39.67
8. Est. Mechanical Eng.Hrs.	144	37.06	0.0	97.90
9. Act. Mechanical Eng. Hrs.	144	24.52	0.0	53.81
10. Est. Electrical Eng. Hrs.	144	24.19	0.0	75.43
11. Act. Electrical Eng. Hrs.	144	11.61	0.0	30.63
12. Est. Architectural Hours	144	30.85	0.0	110.65
13. Act. Architectural Hours	144	17.16	0.0	61.03
14. Est. Technical Supp. Hours	144	0.00	0.0	0.00
15. Act. Technical Supp. Hours	144	9.06	0.0	31.22
16. Est. No. of Skills	144	1.68	1.0	1.11
17. Act. No. of Skills	144	2.15	2.0	1.16
18. Calendar Days to Completion	144	72.26	30.5	94.62
19. Working Days to Completion	144	49.64	21.0	64.72

Figure 7. Statistical Information

the minimum being 51% and the maximum being 108%. Median values have not significance, since not all projects require all skills.

5. Estimated vs. Actual Skills.

Statistical evaluation (rows 18-19) merely indicates that more jobs required an average of two skills than the original estimates indicated. The most probable cause for this observation is that in very few of the cases was the supervisory skill estimated when it was in fact required.

6. Time to Complete

The large difference between the means and medians of both calendar and work days to completion indicates the presence of some large outlying values. It must be remembered that these times represent only the actual time these projects were available to Production Engineering. Data were not readily available to calculate average waiting time in the backlog, the time taken in transmittal of work requests, or time required to perform the work.

D. COST MODEL FORMULATION

"Cost models applied to A&E contract estimation may be beneficial to the EIC in determining 'ballpark' totals to be used as a guide in developing estimates." [Ref. 9] The main emphasis of this study is to develop a general cost model for accurately estimating design time, whether in-house or by an A-E. Unfortunately, the results of regression

analysis (to be discussed in the next chapter) indicated that the current accuracy of estimated design time is within plus or minus 50% of actual design man-hours less than 50% of the time. In order to design a significant cost model, it is necessary first to have a much more significant relationship between estimated and actual design time. Data elements such as the current working estimate, modularity, and complexity were not available. Specific data elements concerning construction (such as number of drawings required and type of facility being worked on) were available in project files but could not be extracted readily and consistently.

V. ANALYSIS

A. EVALUATION OF STATISTICS

1. Supervisory Hours.

The issue of supervisory hours is significant for several reasons. First, supervisory hours were not estimated or recorded for all work requests. Including supervisory hours in total estimated design hours decreased the accuracy for overestimated projects, because those supervisory hours added even more hours to an already excessive estimate. Conversely, including supervisory hours in total estimated design hours increased the accuracy of underestimated projects. Second, including the supervisory hours resulted in an average difference of almost 58% between estimated design hours and actual design hours as compared to an average difference of almost 49% without including supervisory hours in the estimate. For the above reasons, further analysis will be conducted by using only the figures pertaining to estimated design hours <u>excluding</u> supervisory hour estimates. it must be noted that, beginning in FY86, PWC Great Lakes began estimating supervisory hour requirements for all projects.

2. Single vs. Multi-Skill Projects.

As a general rule, projects requiring more than one skill also require more design man-hours and reflect an

increase in the complexity of design. At the very least, there tends to be a certain amount of time used to provide coordination between engineering disciplines. The database revealed that two-thirds of the time the Engineer-in-Charge (EIC) estimated a single-skill requirement when actually the project required more skills. The assumption was made that supervisory requirements, administrative requirements, and engineering technician requirements were skills requiring estimation as well as the standard engineering disciplines. this assumption largely accounts for the large disparity between estimated number of single-skill projects and multi-skill projects (almost two-thirds of projects designed actually used more than one skill). The remainder were differences in the number of skills required in multi-skill projects. Intuitively, the underestimate of skills required to design a project would indicate the necessity of more estimated design hours. In reality, however, over two-thirds of the work requests examined were overestimated. This difference, therefore, is deemed to have little effect on design costs.

3. Over- and Underestimated Hours.

The findings in this area were among the most significant of the entire study. A summary of over- and underestimated hours by plus/minus percentage ranges is shown in Figure 8 reveals the accuracy of the estimation

ESTIMATION ERROR
(percentage ranges)

	# of Project	Percentage
Estimation Error > ± 100%	43	29.9
Estimation Error < ± 100%	101	70.1
Estimation Error < ± 75%	91	63.2
Estimation Error < ± 50%	76	52.8
Estimation Error < ± 25%	53	36.8
Estimation Error < ± 10%	18	12.5
Estimation Error < ± 5%	10	6.9

Figure 8. Estimation Error (percentage ranges)

procedures as they currently exist. Seventy percent of the time actual design hours will be within a range as wide as plus or minus 100% of estimated design hours. This means that 70% of the time a work request actually requiring 100 hours to design will result in an estimate between 0 and 200 hours. The remainder of the time the estimate will be greater than 200 hours. Only in approximately 53% of projects will estimated design hours be within a range of plus or minus 50%.

Since funds are issued to PWC based upon the estimated design hours, the potential for providing too much or too little funding is significant. As has already been seen, nearly two-thirds of all estimates overestimate design hours. Therefore, PWC holds significant amounts of customer funds only to return them at a later date. While PWC holds these funds, the customers are unable to use money that will eventually be returned to them. In many cases money returned late in the fiscal year comes too late for the customer to spend or otherwise obligate efficiently or legally. Such money is lost to the customer (generally to the customer's major claimant). The effects on future years' budgets is not positive. The effect of underestimating design hours by a significant amount is just as bad and possibly even worse. In order to complete the design, more design hours must be paid for. In general,

the customer must pay for these. This requires the customer to immediately reprogram the current budget to provide extra design funds. In most cases this means taking money planned for the construction of the project and using it for design. The general effect is to increase the total cost of construction to the customer.

The fiscal effect of estimation errors is significant. overestimating occurred on two-thirds of the projects designed. By applying a $30 per man-hour billing rate to the total overestimated man-hours (7,341.3 hours, representing 100% of the overestimated hours) the amount of overfunding was calculated at $220,239. At the current performance level of achieving estimates within 50% approximately one-half the time, the overestimated hours would still result in PWC holding excess funds of $200,655. A more desirable range would be to estimate within 25%, which would result in holding excess funds of $209,445 when overestimates occur. Underestimates occurred on the remaining one-third of the projects. A parallel analysis reveals the total underestimated man-hours to equal 1,941.2 hours, resulting in cost overruns totaling $58,236. At the 50% and 25% performance ranges, cost overruns would amount to $20,421 and $43,356, respectively. While these numbers do not appear to be large, they do not reflect the entire FY85 workload. In addition, these are aggregate numbers.

The effect on individual customers could be quite significant in terms of their budgets. These activities may not be able to accommodate such differences.

In comparing the above calculations with Figure 6 (Chapter IV), a very interesting observation is made. While only 53% of the projects are estimated outside plus or minus 50% of actual design hours, these projects account for 79% of the total over- and underestimated hours.

From PWC's perspective, the issue of over- and underestimating design man-hours leads to difficulty in scheduling work requests for design. The scheduling of work requests is done according to estimated design hours. According to the results listed above, any schedule made by Production Scheduling Division or by Production Engineering stands an extremely good chance of being inaccurate the moment it is printed. Although scheduling will be discussed in more detail later, it is obvious that productivity suffers because of inaccurate estimating. Most work requests are overestimated. This leads to engineers, technicians,and administrative assistants awaiting work. This waiting time is non-productive. Production Engineering has only a certain amount of non-productive time budgeted, and this is also used as one measure of performance. This time is then included in the overhead rate. The great temptation is to charge non-productive time to specific

work requests that have not actually been worked on. In effect, this practice would lower PWC costs while increasing the cost to the customer. In studying PWC, Great Lakes, no evidence of this practice was found.

4. Regression Analysis

Regression analysis was conducted in an attempted to measure the reliability of estimated design hours in predicting actual design hours. Several steps were taken in the regression process. First, total estimated design hours were regressed against total actual design hours. Second, to improve the "goodness of fit", standard data transformations (detailed in Figure 9) were performed on both estimated and actual design hours and then regression was performed again. third, multiple linear regression was used to evaluate individual skill estimates against total actual design hours. The same types of data transformations used previously were again used to evaluate the true significance of the regression process. Finally, the projects were stratified into three size groups based upon man-hours (0-100, 101-300, and over 300). Regression was again performed to observe the relationship between estimated design hours and actual design hours. The measure used to evaluate the results of regression was the coefficient of determinations (r^2). r^2 represents the percentage variation

REGRESSION RESULTS

EHS:	Estimated Hours w/supervisory hours
EH:	Estimated Hours w/o supervisory hours
AH:	Actual Hours
E421:	Estimated Civil Engineer Hours
E422:	Estimated Mechanical Engineer Hours
E423:	Estimated Electrical Engineer Hours
E424:	Estimated Architect Hours

Independent Variable(s)	Dependent Variables	R^2
HS	AH	.204
Square Root of EHS	Square Root of AH	.381
Natural Log of EHS	Natural Log of AH	.447
EH	AH	.209
Square Root of EH	Square Root of AH	.317
Natural Log of EH	Natural Log of AH	.425

MULTIPLE REGRESSION

E421, E422, E423, E424	AH	.289
E421, E422, E424	AH	.289
E421, E422	AH	.283

Figure 9. Regression Results

(from the mean) of the dependent variable that can be explained by the independent variable.

Figure 9 provides a tabular presentation of the results of the regression attempts. One significant finding is that the inclusion of supervisory hours improves the ability to predict actual hours. The purpose of the data transformations performed was to provide both dependent and independent variables with distributions that more closely approximated the normal distribution. The rise in the coefficient of determination indicates that the natural logarithmic transformation provided the greatest correlation, Nevertheless, it must be observed that the predictive ability of estimated design hours is below 50%, even with transformed data. Using the raw data just as they were collected indicates a reliability of only 20%. While these result indicate the existence of some relationship, it is not reliable enough to use for predicting. It is clear that there may be other independent variables missing from the model. It was stated earlier that some possibilities were current working estimate, project complexity, and number of drawings required.

Multiple regression was attempted by using the estimates for individual engineer skills as independent variables. the best r^2 value attained was 28.9% using all skills but administrative and technicians. Data

transformations yielded no increases in the coefficient of determination. The implication here is that using aggregate man-hour estimates rather than estimates by individual skills provides greater predictive ability. Still, the overall reliability of estimates is only 44.7% at best, when the natural log transformation is used.

B. ANALYSIS OF WORK REQUEST MANAGEMENT PROCEDURES

1. Work Request Evaluation Procedures.

The most positive finding of the study was that the work request evaluation procedures are very effective. PWC insures that representatives of all parties concerned are present at the weekly meeting of the screening committee (The composition of this committee was listed in Chapter II). This fact alone insures that each work request gets a fair and equitable treatment. In addition, it allows for negotiation, reassignment, and readjustment of work requests. Negotiation is necessary when a work request hasn't been sufficiently defined to allow PWC to understand what work is being requested. Reassignment is necessary when either the design backlog or the shop work backlog is too great to provide timely service. In the first case, an A-E will be engaged to perform design; and, in the second case, a contract will be awarded for work performance.

The evaluation procedure for deciding which design force to use needs clarification. Listed below are the

factors which are evaluated in making the decision between PWC design forces and A-E design forces:

- size of job
- complexity of job
- current skill inventory (in-house)
- current design backlog
- NAVFAC goals (20% PWC design: 80% A-E design)
- current A-E load
- training requirements

Currently the head of Production Engineering subjectively evaluates each work request with respect to the stated factors. For example, the size of the job may be large enough to indicate the use of an A-E firm but training requirements for new engineers and technicians dictate performing the design by in-house forces. The evaluation of all these factors becomes totally subjective because there are no written guidelines and there is no formal decision-making model or procedure currently established.

Assigning strict numerical values to these factors is almost impossible, To force a numerical weighting system upon these factors might be effective, but it would still be based upon subjective assumptions. Until further analysis can be accomplished a decision model should be used that addresses all factors, while taking into account as many subjective assumptions as possible.

2. <u>Production Scheduling Procedures for Production Engineering</u>.

Production scheduling actually takes place in two stages for project design. First, production Scheduling (Code 350) schedules work to be released to Production Engineering on a weekly basis [Ref. 4]. Second, Production Engineering schedules daily work for the following week based upon manpower availability, skill requirements of current projects, and the priority of projects available for design [Ref. 6]. Each week Production Engineering forwards a report of manpower availability to Production scheduling. Based upon this report, the current status of projects being designed, and the priority (and number) of work requests in the backlog, the scheduler provides a list of current projects already working and new projects to be started. This schedule is prepared so that the man-hours for the amount of work assigned are equivalent to 50% of the available man-hours. The schedule is provided to Production Engineering. The EIC then schedules each work request on the basis of the skills required to perform the design, availability of those skills, and priority of the request. this internal schedule is based upon 80% of the available man-hours.

There are two major discrepancies in this process. First, Production Schedules projects based solely upon <u>total</u> design hours estimated for each project, without regard to

specific skills, In addition, the schedule is based only upon 50% of reported available man-hours. By not scheduling with respect the skills required on a particular project, the total man-hours available may numerically fill Production Engineering's schedule, when in fact one skill (Civil Engineering, for instance) may be overloaded and another skill (Mechanical Engineering) may have nothing scheduled. In addition, the 50% limitation may leave many engineers and technicians idle. The second major discrepancy is the fact that Production Engineering does its scheduling based upon 80% of available man-hours and this schedule takes into account the requirements for each engineering discipline. The resultant situation can be illustrated by a brief example.

Suppose that, for a given week, Production Engineering has 500 total man-hours available for design (100 for each discipline, Civil, Mechanical, Electrical, Architectural, and Technical Support). Production Scheduling will schedule only 250 hours of projects without regard to individual skills' availabilities. Assuming an equal distribution of skill requirements, this provides 50 hours of work for each discipline. The EIC receives the schedule, reviews it and then attempts to schedule 80% of the 500 available hours (or 400 hours). Still assuming an equal distribution between disciplines, the EIC discovers that there is a 30 hour discrepancy per discipline.

In the past, the above situation has resulted in the EIC requesting more projects from the scheduler. Communication problems have developed between the two divisions as a result of the difference in scheduling procedures. It is necessary for both procedures to take place. What is also necessary is to schedule from the same assumptions as much as is possible. In addition, the basis of scheduling needs to be changed.

3. Backload Management

There are two backlogs managed at PWC. The first backlog is that of work awaiting performance by PWC shops. The second backlog is that of work awaiting design by Production Engineering. Periodic reviews of these backlogs take place during screening committee meetings. The sizes of the backlogs and estimated waiting time before work begins are evaluated. When the backlog becomes too large, the screening committee recommends he reassignment of work. Work awaiting shop performance is put into contracts and performed by civilian contractors. Work awaiting PWC design is combined and sent to A-E firms for design completion. This practice is an excellent means of providing faster service. Current practice is extremely effective in managing the size of the backlog.

C. EVALUATION OF PRODUCTION ENGINEERING PRACTICES

1. Internal Organization.

The internal organization previously charted (Figure 2) was changed beginning in FY86. Production Engineering moved to a matrix organization, as presented in Figure 10. Under the old organizational structure, projects were assigned by the EIC to the engineer with the "lead discipline". The lead discipline generally had the greatest number of estimated design hours and, therefore, became responsible for scheduling, coordination, and effective use of support by engineering technicians under his direction. Under this system, each engineering discipline had a somewhat stable work force. The difficulty with this system was that the EIC was responsible to track projects through many different engineers. Also, engineers in the same discipline had to compete for the same technical support. Conflict arose over which project engineering technicians would work on first. The resulting confusion adversely affected productivity. [Ref. 1]

The new organization presents 4 EIC's who secure and manage teams of engineers and engineering technicians assigned to specific products. In arranging these teams, there is competition for the most productive workers. Once a worker is assigned, however, he remains on that team until

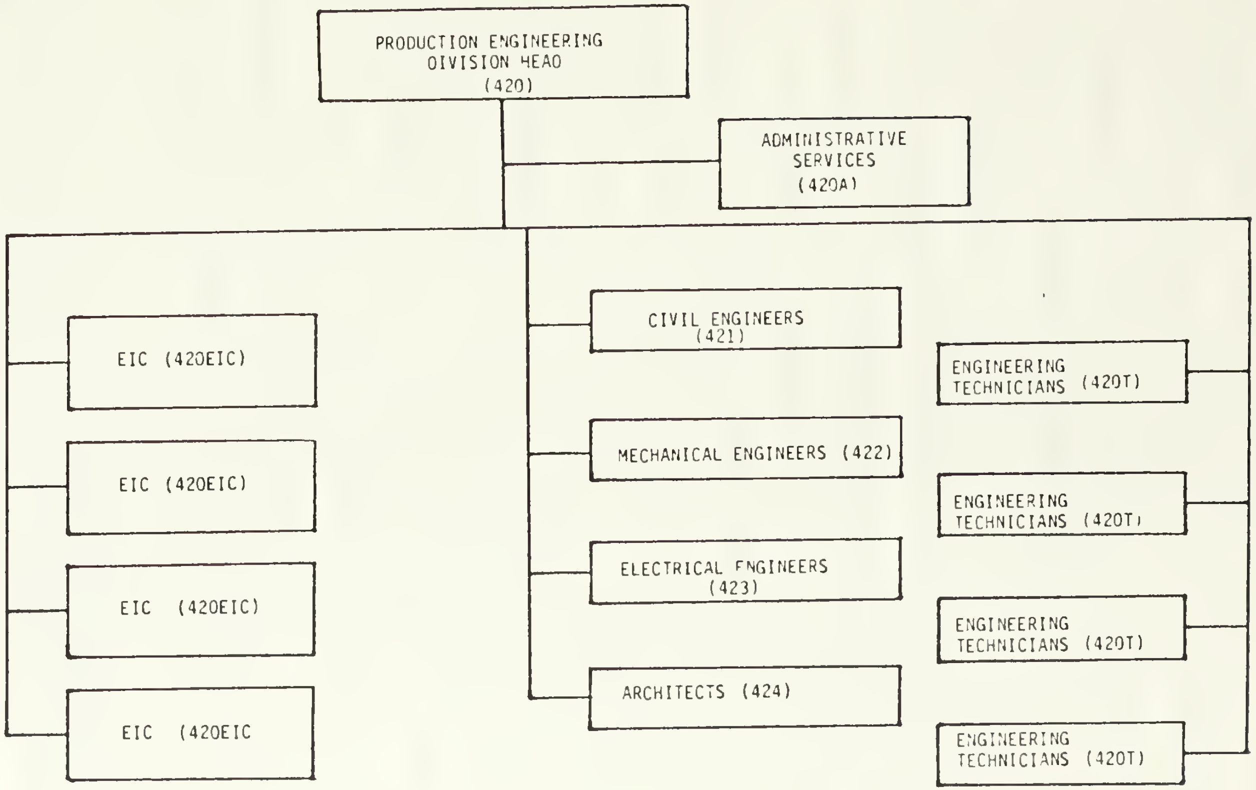

Figure 10. Internal Organization FY86

project design is completed. The EIC's schedule work that comes to them and are responsible for insuring timely completion of design. Any one person may be on more than one design team, but team designations are strongly associated with the projects; so, conflicts concerning what work to do first should be reduced. In addition, since EIC's compete for design resources, questionable performers are quickly identified, since competition is keenest for productive personnel. Furthermore, beginning 1 October 1986, all drawings, plans, and specifications must be signed by the engineer responsible for them. This signature represents the engineer's "liability" for the design contained in these documents. The expectations of this signature requirement are that it will improve the engineers' quality control efforts, and in doing so, will increase the quality of design. [Ref. 1]

The goals of this reorganization are to improve productivity, to improve quality of design, and to reduce the unit cost of design.

2. <u>In-House vs. A-E Design</u>

Appendix A displays the progress that PWC, Great Lakes has made toward achieving the NAVFAC goals for contract design stated previously. Nearly every person interviewed at PWC, Great Lakes agreed that 20% in-house design and 80% A-E design was an ambitious goal. The

consensus opinion between engineers and managers was that 40% in-house and 60% A-E design is a more realistic target. The reasoning behind these figures is that competition for quality engineers is high. In order to attract and maintain the best young engineers, enough "good" work must be maintained in-house to motivate them. "Good" work is generally the larger (sometimes more prestigious) projects requiring engineering challenges and learning opportunities. These projects are, for the most part, automatically designated for A-E design. If the NAVFAC goal is actively pursued, the remaining design tends to be small, repetitive, unchallenging work. Intuitively, this might indicate a savings in design time. Unfortunately, most of the buildings and facilities at Great Lakes are of very old design and structure requiring historical knowledge and/or experience in their special problems. This is not the most attractive type of work for training new engineers.

Figure 11 displays a recommended decision process to evaluate the decision to perform design by using either an A-E firm or in-house design resources. The decision variables are ranked in order of importance to PWC as a whole. The same ranking would not necessarily be given by Production Engineering. This process is already being performed by the decision head of Production Engineering. By presenting this in a graphic form, each decision can be

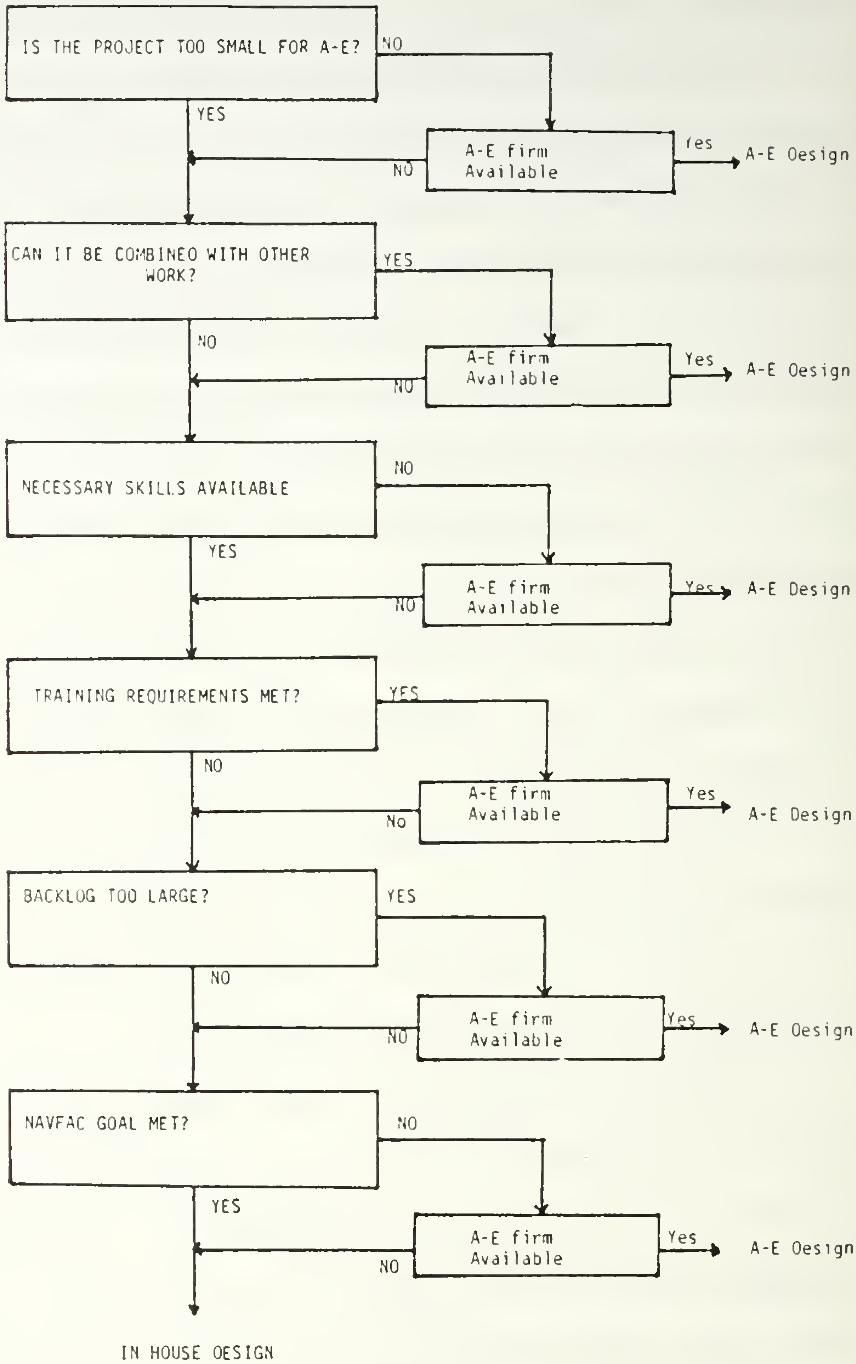

Figure 11. Recommended Decision Process

documented to discover patterns in decision-making. While monetary savings are not a direct result, better decision-making may lead to more efficient use of design resources.

3. Design Equipment

In FY85 PWC began the acquisition of Computer Aided Design and Drafting (CADD) equipment. This equipment is a computer system designed to allow faster, more reliable, and more accurate design. Appendix C provides more specific description and capabilities. At the time of this study only one of six work stations had been installed. The dollar savings on the 18 projects already completed using the CADD were over $26,000. These savings represented drafting alone, as engineering services won't be performed until all six stations are available. Estimated yearly cost savings are $80,000 for each work station. Further cost savings are planned because the accuracy of drawings and designs performed on the CADD are expected to reduce significantly the number and cost of change orders on contracts. These savings have been estimated at $150,000 per year. The utility of this system alone will greatly increase the productivity of Production Engineering.

VI. CONCLUSIONS AND RECOMMENDATIONS

A. SUMMARY

The amount of design work at PWC, Great Lakes is large and requires an efficient design decision-making process and a productive design force to provide timely, quality service. The development and documentation of a decision process is essential to effective use of the design resources available. Of more immediate importance is the improvement of productivity within the Production Engineering Division. Steps have already been taken by reorganization and by the acquisition of technologically advanced design equipment. Further improvements will be achieved by the implementation of the recommendations contained in this thesis.

B. CONCLUSIONS

1. Work Request Evaluation.

The evaluation of each work request by the Screening Committee and subsequently by the Production Engineering division head is the most positive strength in the management system. The diagram of work flow presented in Chapter II provides the flexibility for modifications in the face of future refinements of the organization and policy changes affecting the flow of work.

2. Design Man-hour Estimation.

Current accuracy in estimating design man-hours requires improvement. With less than 50% of man-hour estimates falling within plus or minus 50% of actual design man-hours, there is something amiss with current estimation procedures. The intent of this study was to develop a statistically valid man-hour estimation model based upon historical data. The specific estimation techniques used were not studied. Thus, no conclusions were reached as to the cause of estimation difficulties.

The practical significance of inaccurate design man-hour estimations is that an overestimate of man-hours result in overfunding a project. PWC then holds these extra funds until design is complete. Thus, these funds are useless for other purposes by customers, until such time as the design is completed and the overestimate is recognized. That may be too late in the fiscal year for the funds ever to be used. Since must of the work is loaded toward the end of the fiscal year, the potential loss of funds due to overestimated design man-hours is great. Underestimated projects represent cost overruns. When PWC exceeds estimated man-hours and requires more funds, the customer must immediately reprogram funds to continue the design or drop the project until another time. While only occurring approximately 33%

of the time, such cost overruns may be significant to the individual customer's budgets.

From PWC's viewpoint, scheduling is done based upon the estimated design man-hours. Inaccurate estimates render schedules ineffective. Communication difficulties between Production Management and Production Engineering are brought on by the difference in Production Management's scheduling procedures and scheduling procedures internal to Production Engineering. (The scheduler schedules 50% of available man-hours while Production Engineering schedules to 80% of available man-hours.) These differences must be resolved by management at PWC. The resolution of these problems will result in smoother operations and increased productivity through better scheduling.

3. Design Equipment.

PWC is already aware of the potential in Computer Aided Design and Drafting (CADD). It should expedite the procurement of the CADD system, although the cost savings projections appear to be slightly understated. A savings of more than $26,000 has been documented on 18 complete design projects using the CADD only for the drafting portion of design. By extending this rate of savings to cover 144 projects (comparable to the database analyzed), over $200,000 in savings would result, When all 6 work stations are installed, the cost savings should indeed be

significant. The effect on productivity should be very great. Customers will benefit ultimately by reduced cost for design and a better quality product.

C. RECOMMENDATIONS

There are two recommendations that can be made as a result of the research in this thesis. First, PWC should adopt and document the use of the A-E vs. in-house decision model (or some variant of the model) proposed in Chapter V (Figure 10). This will provide PWC an indication of the pattern of decision-making within Production Engineering. It will also provide a greater awareness of the relationship with NAVFAC goals and with internal considerations such as training requirements and skill availability. The model presented is easily modified to reflect any changes in policy, organization, or priority of factors contained in the model. Using this model as a decision-making form included in each project folder would allow documentation of the decision process. A database could be constructed to evaluate the decision-making process.

Second, PWC should address the estimation process for design hours. Reference 7, a study done for the Air Force, proposes to make design hour estimation a performance criterion for engineers. A copy of this study should be procured and examined for further suggestions on the improvement of estimation. PWC should also procure a copy

of the thesis, Cost Estimation of Architect & Engineer Contracts, [Ref. 9]. This thesis contains an analysis of A-E contract design estimation procedures at Western Division, Naval Facilities Engineering Command. The statistical model contained therein could be of some use in developing a predictive model for use at PWC, Great Lakes. This thesis is available from the Defense Technical Information Center (The address is contained in the distribution list at the end of this thesis).

D. FUTURE RESEARCH

Several areas are recommended for future research, First, with the acquisition of the CADD system, documentation is already being kept concerning any reduction in the amount of change orders on awarded contracts. A study of change orders on contracts designed using the CADD system would provide information significant to design organizations throughout the Navy.

Second, the cost of in-house design and the development of a cost estimating model is still of primary importance. The requirement in this case is so urgent and such a large task that it is difficult to undertake with only one person. A team of analysts with direct and frequent access to necessary records, reports and publications is required.

APPENDIX A

DESIGN RESOURCE COMPARISONS

DESIGN RESOURCE COMPARISONS

FY-81	QTR 1	QTR 2	QTR 3	QTR 4	TOTAL
DIRECT LABOR HRS	6,412	6,362	6,699	6,724	26,197
I-H COSTS	141,064	139,964	147,378	147,928	576,334
A&E FEE					25,800
TOTAL COSTS					602,134
I-H PERCENTAGE					96%
A&E PERCENTAGE					4%

FY-82	QTR 1	QTR 2	QTR 3	QTR 4	TOTAL
DIRECT LABOR HRS	6,717	6,569	6,413	6,926	26,625
I-H COSTS	159,596	156,079	152,373	164,542	632,610
A&E FEE			51,400	14,630	66,050
TOTAL COSTS	159.596	156.079	203.773	179,192	698,640
I-H PERCENTAGE					91%
A&E PERCENTAGE					9%

FY-83	QTR 1	QTR 2	QTR 3	QTR 4	TOTAL
DIRECT LABOR HRS	6,582	6,294	7,533	8,224	28,633
I-H COSTS	170,211	162,763	194,803	212,673	740,449
A&E FEE	32,589	115,410	169,439	290,013	607,451
TOTAL COSTS	202,800	278,173	364,242	502,686	1,347,900
I-H PERCENTAGE					55%
A&E PERCENTAGE					45%

FY-84	QTR 1	QTR 2	QTR 3	QTR 4	TOTAL
DIRECT LABOR HRS	6,985	11,256	12,646	9,755	40,642
I-H COSTS	180,632	291,080	327,025	252,264	1,051,001
A&E FEE	264,880	228,560	101,525	386,862	981,825
TOTAL COSTS	445,512	519,640	428,550	639,124	2,032,826
I-H PERCENTAGE					52%
A&E PERCENTAGE					48%

FY-85	QTR 1	QTR 2	QTR 3	QTR 4	TOTAL
DIRECT LABOR HRS	10,168.4	10,397.0	11,057.5	11,569.1	43,191
I-H COSTS	320,610	327,610	348,611	364,774	1,361,812
A&E FEE	53,867	124,330	203,465	519,419	901,081
TOTAL COSTS	374,477	452,147	552,076	884,193	2,262,893
I-H PERCENTAGE					60%
A&E PERCENTAGE					40%

APPENDIX B
DATABASE

Explanation of Column Headings

t-hrs:	Total estimated hours (including supervision)
t-hrsa:	Total estimated hours (excluding supervision)
420a:	Estimated administrative hours
421:	Estimated civil engineer hours
422:	Estimated mechanical engineer hours
423:	Estimated electrical engineer hours
424:	Estimated architectural hours
420t:	Estimated technical support hours
code:	Key code (codes listed below)

1: PWC shop work

2: Contractor work

3: Service contract

4: A-E preparation

5: Minor construction

6: Surveys

7: Preliminary Estimate

8: Master Planning

9: MILCON (Military Construction)

10: Drawings

11: Design review/other

eskl: Estimated number of design skills required

askl: Actual number of design skills required

acthrs: Actual design hours

a420a: Actual Administrative hours

a421: Actual civil engineer hours

a422: Actual mechanical engineer hours

a423: Actual electrical engineer hours

a424: Actual architectural hours

a420t: Actual technical support hours

cdc: calendar days to complete project

wdc: work days to complete project

ROW	t-hrs	t-hrsa	420a	421	422	423	424	420t	code	eskl	askl	acthrs	a420a	a421	a422	a423	a424	a420t	cdc	wdc
1	18	16	0	4	4	4	4	0	11	4	3	8.0	0.0	3.0	4.0	0.0	1.0	0.0	3	3
2	96	88	0	88	0	0	0	0	11	1	2	150.0	6.0	136.0	0.0	8.0	0.0	0.0	190	130
3	128	120	0	120	0	0	0	0	1	1	1	104.0	0.0	0.0	104.0	0.0	0.0	0.0	201	138
4	868	860	0	240	500	120	0	0	2	3	5	1142.5	27.5	294.0	338.0	191.0	0.0	292.0	205	140
5	160	152	0	152	0	0	0	0	2	1	1	75.0	5.0	70.0	0.0	0.0	0.0	0.0	36	25
6	108	100	0	100	0	0	0	0	2	1	1	53.0	5.0	48.0	0.0	0.0	0.0	0.0	32	22
7	40	32	0	32	0	0	0	0	6	1	1	29.0	0.0	29.0	0.0	0.0	0.0	0.0	87	60
8	36	32	0	32	0	0	0	0	6	1	1	28.0	0.0	28.0	0.0	0.0	0.0	0.0	18	12
9	80	72	0	72	0	0	0	0	2	1	1	97.0	5.0	93.0	0.0	0.0	0.0	0.0	176	121
10	70	70	0	70	0	0	0	0	1	1	1	48.0	0.0	48.0	0.0	0.0	0.0	0.0	20	14
11	32	32	0	32	0	0	0	0	6	1	1	35.5	0.5	35.0	0.0	0.0	0.0	0.0	27	19
12	128	120	0	120	0	0	0	0	2	1	3	102.5	1.0	95.5	0.0	6.0	0.0	0.0	28	19
13	32	24	0	24	0	0	0	0	6	1	1	6.5	0.5	6.0	0.0	0.0	0.0	0.0	4	4
14	48	40	0	40	0	0	0	0	2	1	2	33.5	1.0	32.5	0.0	0.0	0.0	0.0	125	86
15	72	64	0	64	0	0	0	0	1	1	2	53.5	0.5	50.0	0.0	3.0	0.0	0.0	29	20
16	64	56	0	56	0	0	0	0	6	1	2	24.5	0.5	24.0	0.0	0.0	0.0	0.0	122	84
17	20	12	0	12	0	0	0	0	6	1	1	10.5	0.0	10.5	0.0	0.0	0.0	0.0	12	8
18	6	5	0	5	0	0	0	0	6	1	1	2.0	0.0	2.0	0.0	0.0	0.0	0.0	1	1
19	88	80	0	80	0	0	0	0	7	1	1	30.0	0.0	30.0	0.0	0.0	0.0	0.0	32	22
20	268	260	0	60	100	100	0	0	2	3	2	69.5	0.0	63.5	0.0	6.0	0.0	0.0	49	34
21	7	7	0	7	0	0	0	0	1	1	1	22.0	0.0	22.0	0.0	0.0	0.0	0.0	16	11
22	20	12	0	12	0	0	0	0	6	1	1	6.5	0.0	6.5	0.0	0.0	0.0	0.0	5	5
23	308	300	0	300	0	0	0	0	2	1	1	295.5	3.5	292.0	0.0	0.0	0.0	0.0	66	45
24	6	4	0	4	0	0	0	0	6	1	1	4.0	0.0	4.0	0.0	0.0	0.0	0.0	2	2
25	32	24	0	24	0	0	0	0	6	1	2	40.5	0.0	29.5	0.0	0.0	0.0	11.0	30	21
26	48	40	0	40	0	0	0	0	11	1	1	20.5	0.0	20.5	0.0	0.0	0.0	0.0	5	5
27	188	180	0	180	0	0	0	0	2	1	2	84.0	9.0	75.0	0.0	0.0	0.0	0.0	34	23
28	56	48	0	48	0	0	0	0	1	1	1	33.0	0.0	33.0	0.0	0.0	0.0	0.0	7	5
29	24	22	0	22	0	0	0	0	6	1	2	12.5	0.5	12.0	0.0	0.0	0.0	0.0	4	4
30	108	100	0	100	0	0	0	0	2	1	2	32.0	18.0	14.0	0.0	0.0	0.0	0.0	73	50
31	40	32	0	32	0	0	0	0	6	1	1	3.0	0.0	3.0	0.0	0.0	0.0	0.0	1	1
32	36	32	0	0	32	0	0	0	6	1	2	28.0	1.0	0.0	27.0	0.0	0.0	0.0	13	9
33	584	584	0	0	520	0	64	0	1	2	4	239.0	0.0	0.0	80.0	4.0	124.0	31.0	228	156
34	320	320	0	30	290	0	0	0	2	2	5	218.5	2.0	22.0	160.0	14.0	17.0	3.5	89	61
35	56	48	0	0	40	8	0	0	4	2	1	25.0	0.0	0.0	25.0	0.0	0.0	0.0	64	44
36	248	240	0	0	240	0	0	0	1	1	2	286.0	1.5	0.0	232.5	0.0	0.0	52.0	279	191
37	84	76	0	0	60	8	8	0	4	3	2	38.5	1.0	0.0	37.5	0.0	0.0	0.0	21	14
38	392	384	0	64	320	0	0	0	1	2	2	34.0	2.0	0.0	32.0	0.0	0.0	0.0	50	34
39	8	8	0	0	8	0	0	0	2	1	2	28.0	0.0	0.0	24.0	0.0	0.0	4.0	3	3
40	132	124	0	40	40	20	24	0	4	4	5	104.0	1.0	8.5	76.0	14.0	4.5	0.0	189	129
41	48	40	0	0	40	0	0	0	6	1	2	34.5	0.5	0.0	34.0	0.0	0.0	0.0	9	6
42	56	48	0	0	40	8	0	0	6	2	1	53.0	0.0	0.0	53.0	0.0	0.0	0.0	28	19
43	68	64	4	0	60	0	0	0	6	2	1	67.5	0.0	0.0	67.5	0.0	0.0	0.0	32	22
44	55	55	0	0	55	0	0	0	4	1	2	37.5	1.5	0.0	36.0	0.0	0.0	0.0	339	232
45	158	150	0	0	150	0	0	0	6	1	4	222.5	4.0	1.0	178.5	0.0	0.0	39.0	238	163
46	60	60	0	10	30	20	0	0	4	3	2	87.0	0.0	11.0	76.0	0.0	0.0	0.0	25	17
47	40	40	0	0	40	0	0	0	4	1	3	65.0	1.0	0.0	23.0	0.0	0.0	41.0	196	134
48	32	32	0	0	32	0	0	0	6	1	1	15.0	0.0	0.0	15.0	0.0	0.0	0.0	15	10

ROW	t-hrs	t-hrsa	420a	421	422	423	424	420t	code	eskl	askl	acthrs	a420a	a421	a422	a423	a424	a420t	cdc	wdc
49	90	90	0	0	90	0	0	0	4	1	3	413.0	1.5	0.0	297.5	0.0	0.0	114.0	212	145
50	38	38	0	0	30	8	0	0	4	2	1	5.0	0.0	0.0	5.0	0.0	0.0	0.0	1	1
51	40	40	0	0	40	0	0	0	6	1	1	31.5	0.0	0.0	31.5	0.0	0.0	0.0	14	10
52	72	72	0	16	56	0	0	0	2	2	4	155.0	2.0	0.0	150.0	0.0	0.0	3.0	86	59
53	188	188	0	110	46	8	24	0	4	4	5	534.0	21.5	68.5	183.5	116.5	0.0	144.0	161	110
54	48	40	0	0	40	0	0	0	6	1	2	33.5	1.0	0.0	32.5	0.0	0.0	0.0	11	8
55	48	40	0	0	40	0	0	0	6	1	2	50.5	1.5	0.0	49.0	0.0	0.0	0.0	30	21
56	74	66	0	8	50	8	0	0	7	3	1	7.0	0.0	0.0	7.0	0.0	0.0	0.0	19	13
57	88	80	0	0	80	0	0	0	1	1	3	28.0	1.0	0.0	15.0	0.0	0.0	12.0	22	15
58	168	160	0	20	100	40	0	0	7	3	5	223.0	1.0	7.0	151.5	41.5	0.0	22.0	289	198
59	116	108	0	0	80	28	0	0	1	2	2	44.0	0.0	0.0	39.0	5.0	0.0	0.0	7	5
60	48	40	0	0	40	0	0	0	1	1	2	35.0	1.0	0.0	34.0	0.0	0.0	0.0	393	269
61	128	120	0	0	120	0	0	0	1	1	1	20.0	0.0	0.0	20.0	0.0	0.0	0.0	6	4
62	30	30	0	0	30	0	0	0	6	1	2	31.0	1.0	0.0	30.0	0.0	0.0	0.0	49	34
63	90	90	0	0	80	10	0	0	11	2	2	39.0	1.0	0.0	38.0	0.0	0.0	0.0	36	25
64	24	16	0	0	16	0	0	0	1	1	1	16.0	0.0	0.0	16.0	0.0	0.0	0.0	2	2
65	88	80	0	0	80	0	0	0	1	1	2	64.0	10.0	0.0	54.0	0.0	0.0	0.0	35	24
66	30	30	0	0	30	0	0	0	4	1	1	29.0	0.0	0.0	29.0	0.0	0.0	0.0	28	19
67	128	128	0	56	32	0	40	0	1	3	3	48.5	1.0	0.0	46.0	0.0	1.5	0.0	10	7
68	48	40	0	0	40	0	0	0	6	1	1	38.0	0.0	0.0	38.0	0.0	0.0	0.0	12	8
69	48	40	0	0	40	0	0	0	6	1	1	87.0	0.0	0.0	87.0	0.0	0.0	0.0	75	51
70	44	36	0	0	36	0	0	0	6	1	2	44.0	1.0	0.0	43.0	0.0	0.0	0.0	14	10
71	80	72	0	0	72	0	0	0	7	1	1	68.0	0.0	0.0	68.0	0.0	0.0	0.0	23	16
72	68	60	0	0	60	0	0	0	6	1	1	67.5	0.0	0.0	67.5	0.0	0.0	0.0	41	28
73	68	60	0	0	0	60	0	0	6	1	1	16.0	0.0	0.0	0.0	16.0	0.0	0.0	13	9
74	152	152	0	0	0	152	0	0	2	1	3	91.5	2.5	0.0	0.0	69.5	0.0	19.5	296	203
75	48	40	0	0	0	40	0	0	1	1	4	114.2	4.0	12.0	0.0	41.7	0.0	56.5	182	125
76	776	768	0	40	0	728	0	0	2	2	4	260.0	1.0	7.0	0.0	215.0	0.0	37.0	283	194
77	150	130	0	0	30	100	0	0	1	2	3	169.0	0.0	0.0	12.0	140.0	0.0	17.0	256	175
78	98	90	0	0	0	90	0	0	2	1	2	63.0	1.0	0.0	0.0	62.0	0.0	0.0	31	21
79	36	28	0	0	0	28	0	0	1	1	3	39.0	1.0	0.0	0.0	29.0	0.0	9.0	19	13
80	10	8	0	0	0	8	0	0	7	1	1	1.5	0.0	0.0	0.0	1.5	0.0	0.0	1	1
81	100	92	0	0	32	60	0	0	1	2	3	25.0	1.0	0.0	0.0	17.0	7.0	0.0	11	8
82	70	66	0	0	0	66	0	0	2	1	3	48.0	1.0	0.0	12.0	35.0	0.0	0.0	17	12
83	20	4	0	0	0	4	0	0	1	1	2	5.0	1.0	0.0	0.0	4.0	0.0	0.0	2	2
84	128	120	0	0	0	120	0	0	1	1	3	108.0	1.0	0.0	0.0	67.5	0.0	39.5	166	114
85	20	20	0	0	20	0	0	0	6	1	2	21.5	1.5	0.0	0.0	20.0	0.0	0.0	14	10
86	58	30	0	0	0	30	0	0	1	1	2	24.0	0.0	0.0	0.0	24.0	0.0	0.0	4	4
87	58	30	0	0	0	30	0	0	1	1	2	46.5	0.0	0.0	0.0	22.5	0.0	24.0	31	21
88	68	60	0	0	0	60	0	0	1	1	2	18.5	1.0	0.0	0.0	17.5	0.0	0.0	3	3
89	168	160	0	0	0	160	0	0	1	1	2	24.0	0.0	0.0	0.0	8.0	0.0	16.0	8	6
90	58	50	0	0	0	50	0	0	1	1	4	61.5	1.0	0.0	0.0	21.5	0.0	39.0	99	68
91	68	60	0	0	0	60	0	0	1	1	3	123.5	0.0	0.0	0.0	18.0	0.0	105.5	68	47
92	68	60	0	0	0	60	0	0	1	1	1	40.5	0.0	0.0	0.0	40.5	0.0	0.0	60	41
93	58	50	0	0	0	50	0	0	1	1	2	55.5	0.0	0.0	0.0	28.5	0.0	27.0	5	5
94	58	50	0	0	0	50	0	0	1	1	2	43.0	0.0	0.0	0.0	6.0	0.0	37.0	93	64
95	68	60	0	0	0	60	0	0	1	1	2	50.0	0.0	0.0	0.0	22.5	0.0	27.5	70	48
96	62	60	0	0	0	60	0	0	1	1	2	57.5	0.0	0.0	0.0	29.5	0.0	28.0	74	51

ROW	t-hrs	t-hrsa	420a	421	422	423	424	420t	code	eskl	askl	acthrs	a420a	a421	a422	a423	a424	a420t	cdc	wdc
97	68	60	0	0	0	60	0	0	6	1	2	36.0	1.0	0.0	0.0	35.0	0.0	0.0	18	12
98	32	24	0	0	0	24	0	0	7	1	1	20.0	0.0	0.0	0.0	20.0	0.0	0.0	7	5
99	68	60	0	0	0	60	0	0	1	1	2	44.0	0.0	0.0	0.0	42.0	0.0	2.0	69	47
100	56	40	0	0	0	40	0	0	6	1	4	52.0	1.0	0.0	0.0	34.0	5.0	12.0	78	53
101	48	40	0	0	0	40	0	0	2	1	3	94.5	2.5	0.0	0.0	75.0	0.0	17.0	113	77
102	18	16	0	16	0	0	0	0	6	1	1	6.0	0.0	6.0	0.0	0.0	0.0	0.0	8	5
103	76	72	0	8	16	16	32	0	11	4	2	24.0	0.0	0.0	14.0	0.0	0.0	10.0	25	17
104	43	40	0	8	8	8	16	0	11	4	4	25.5	0.5	7.0	8.0	10.0	0.0	0.0	39	27
105	48	40	0	8	8	8	16	0	11	4	3	38.0	0.0	2.0	25.0	10.0	1.0	0.0	84	58
106	76	72	0	8	16	16	32	0	11	4	5	41.0	1.0	8.0	16.0	10.0	6.0	0.0	10	7
107	93	88	0	16	16	16	40	0	11	4	5	51.0	4.0	4.0	16.0	20.0	7.0	0.0	21	14
108	20	16	0	4	4	4	4	0	6	4	3	33.5	0.0	4.5	6.0	2.0	21.0	0.0	23	16
109	88	80	0	16	16	16	32	0	11	4	3	28.0	0.0	0.0	11.0	9.0	8.0	0.0	7	5
110	48	44	0	8	12	8	16	0	11	4	5	56.0	7.0	8.0	12.0	9.0	20.0	0.0	23	16
111	28	24	0	0	0	0	24	0	11	1	3	5.0	2.0	2.0	0.0	0.0	1.0	0.0	30	21
112	28	24	0	0	0	0	24	0	11	1	3	14.5	2.0	2.0	0.0	0.0	10.5	0.0	30	21
113	168	160	0	24	32	24	80	0	4	4	3	131.0	5.0	11.0	16.0	0.0	99.0	0.0	284	195
114	112	104	0	0	0	0	104	0	4	1	2	101.0	0.0	0.0	0.0	0.0	97.0	4.0	244	167
115	106	106	0	8	0	0	98	0	6	1	1	49.5	0.0	0.0	0.0	0.0	49.5	0.0	244	167
116	40	33	0	24	24	15	24	0	7	4	1	26.0	0.0	0.0	0.0	0.0	26.0	0.0	21	14
117	200	192	0	20	8	24	140	0	1	4	3	193.5	1.0	9.0	0.0	0.0	183.5	0.0	33	23
118	236	228	0	28	80	40	80	0	1	4	1	42.0	0.5	0.0	0.0	0.0	41.5	0.0	48	33
119	40	32	0	0	0	0	32	0	6	1	3	78.5	0.5	0.0	0.0	0.0	75.5	2.5	28	19
120	48	40	0	0	0	0	40	0	7	1	1	13.0	0.0	0.0	0.0	0.0	13.0	0.0	29	20
121	32	24	0	0	0	0	24	0	6	1	1	27.0	0.0	0.0	0.0	0.0	27.0	0.0	43	29
122	944	920	0	16	88	16	800	0	1	4	3	798.2	2.0	0.0	151.8	0.0	644.4	0.0	74	51
123	54	46	0	8	10	12	16	0	11	4	3	74.5	0.0	6.5	12.0	8.0	48.0	0.0	89	61
124	68	60	0	60	0	0	0	0	1	1	2	77.0	0.0	2.0	0.0	0.0	75.0	0.0	39	27
125	64	56	0	0	0	0	56	0	1	1	2	27.5	1.5	0.0	0.0	0.0	26.0	0.0	12	8
126	68	60	0	12	0	0	48	0	4	2	2	40.0	3.0	0.0	8.0	0.0	29.0	0.0	14	10
127	150	110	0	0	40	30	40	0	1	3	1	7.5	0.0	0.0	0.0	0.0	7.5	0.0	27	19
128	192	184	0	0	0	0	84	0	1	1	1	43.0	0.0	0.0	0.0	0.0	43.0	0.0	13	9
129	44	36	0	0	12	0	24	0	11	2	1	41.0	0.0	0.0	39.0	2.0	0.0	0.0	12	8
130	56	48	0	0	0	0	48	0	2	1	2	41.0	1.0	0.0	0.0	0.0	40.0	0.0	37	25
131	112	104	0	0	0	0	104	0	2	1	3	121.5	6.0	0.0	0.0	0.0	115.0	0.5	81	55
132	88	80	0	0	20	0	60	0	6	2	3	78.0	0.0	0.0	12.0	8.0	58.0	0.0	41	28
133	116	108	0	28	20	20	40	0	4	4	1	10.0	0.0	0.0	0.0	0.0	10.0	0.0	29	20
134	64	56	0	0	0	0	56	0	6	1	2	42.5	3.5	0.0	0.0	0.0	39.0	0.0	42	29
135	128	120	0	0	0	0	120	0	2	1	1	91.0	0.0	0.0	0.0	0.0	90.0	1.0	28	19
136	136	128	0	8	0	0	120	0	1	2	3	37.5	0.0	6.0	0.0	0.0	30.5	1.0	36	25
137	128	120	0	0	0	0	120	0	1	1	1	18.0	0.0	0.0	0.0	0.0	18.0	0.0	36	25
138	72	72	0	0	0	0	72	0	1	1	1	45.5	0.0	0.0	0.0	0.0	45.5	0.0	19	13
139	364	348	0	16	64	0	268	0	4	3	2	184.5	10.5	0.0	0.0	0.0	174.0	0.0	161	110
140	208	200	0	0	0	0	200	0	4	1	2	14.5	1.0	0.0	0.0	0.0	13.5	0.0	8	5
141	2469	2413	0	188	796	445	984	0	1	4	4	93.0	8.0	74.5	5.0	5.5	0.0	0.0	355	243
142	174	166	0	24	24	16	102	0	4	4	2	38.5	1.5	0.0	0.0	0.0	37.0	0.0	423	290
143	11	11	0	0	0	0	11	0	4	1	1	19.0	0.0	0.0	0.0	0.0	19.0	0.0	36	25
144	88	80	0	12	12	8	48	0	4	4	5	77.5	4.0	1.5	0.0	6.0	62.0	4.0	394	270

APPENDIX C

ABBREVIATED SYSTEM DECISION PAPER (ASDP)

1. The need for this acquisition is to expand the existing Graphic Engineering and Mapping System (GEMS) in the Engineering and Planning Division. All references to GEMS herein after will be Computer Aided Design and Drafting (CADD). The functional requirement of the hardware is to generate engineering drawings in support of maintenance of Naval Shore Facilities. The current methods of drawing generation is through the use of conventional drafting/analysis methods and the utilization of the CADD System which includes a single graphic workstation. the current conventional methods of drawing generation provides minimal possibilities of data exchange and integration for future production projects.

2. The selected alternative is to expand the existing CADD system from one to six workstations. The existing Central Processing Unit (CPU) has the capability to execute ten independent tasks at any one time (includes plotter, remote peripherals, etc.). Many of the existing engineering and technical staff have already completed introductory level training in anticipation of expanding the CADD System to include all authorized personnel. Intermediate level training would begin promptly upon notification from NAVFACHQ of approved subject hardware acquisition. No additional software will be required at this time. Hardware acquired under this request should be installed by 1 October 1986 due to the contractual requirements negotiated by the General service Administration (GSA). Implementation of multi-discipline applications would begin immediately upon installation of requested hardware due to the training completed by existing personnel. Advanced software would not be used until at least FY88.

3. The only two alternatives considered were manual/conventional methods and stand-alone mini-workstations. Manual methods prevent accurate data exchange and integration between Planning, Utility, Security, Engineering and Estimating Divisions within the NAVFAC organization. Stand-alone mini-workstations were not a selected alternative due to existing hardware already in operations and being capable of being expanded upon. It is in the best interest of the Navy, when considering the economics involved, to expand the existing system rather than install new stand-alone workstations.

4. Projected costs are itemized as follows:

Hardware

Instaview Color Workstation (5 @ $39,100) $195,500.00

Maintenance

Full Service Contract (5 @ $3,576) $17,880.00 yr.

Personnel

No additional personnel required

Training

Intermediate level training for approximately 12 people, currently trained at the introductory level, would take place immediately after installation of subject acquisition at the PWC, Great Lakes CADD side (approximate cost $1,500). Computervision is currently under contract with the Navy to provide educational services upon request. These services are provided through NAVFACENGCOM, Alexandria, Code 04M4.

Site Preparation

The following is a list of approximate costs of site preparation that are necessary prior to installation of subject hardware.

A/C Unit	$6,000.00
Dedicated Circuits	$3,000.00
Track Lighting and Instruction	$4,000.00
Door and Installation	$300.00
Security Accessories	$300.00
Window Shades	$400.00
	$14,000.00

Equipment installation will require relocating existing mechanical engineers to a different location of permanent residence. All site preparation and relocation of personnel can be accomplished with shop forces.

Intangible Savings

Cost savings which are forecasted and incalculable are the reduction of change orders, reduction of AE fees, reduction of utility disruptions and database integration within the NAVFAC organization.

Tangible Savings

One of the large paybacks with a CADD System is drafting. Generating drawings on a CADD System versus manual methods requires approximately one-third to one-half the normal time. Based on statistics submitted in enclosure (1), each workstation could save approximately $80,000 per year in drafting support alone (based on $30.00/hr overhead rate). Savings on the reduction of change orders are anticipated to exceed $150,000 per year per workstation. This savings is based on an estimate of 15% of the total CWE for change orders on CADD produced work.

5. The hardware requested in this acquisition will interface with the Computervision Designer V CADDS 4X (w/200X upgrade) processor. No interface problems are anticipated due to sole source hardware acquisition.

6. Funding will be provided by NPWC, Great Lakes upon request. Funding for this acquisition was budgeted for FY 86 and 87.

COMPUTER RESOURCES ACQUISTION (ASDP Supplement)

1. Instaview High resolution Color Interactive Graphics Workstation.

2. The hardware will be located in the Production Engineering Division. Code 420 CADD Area, of Building 1A, Great Lakes, Illinois. This hardware will also be located in a secured area and accessible to authorized personnel only.

3. Point of contract is Mr. Mark T. Heinzen, CADD System Manager, Code 420MH at 312-688-4766/4285.

4. System life is estimated at seven to ten years.

5. Total contract value is estimated at $195,500.00 based on five workstations at $39,100.00 each.

6. Workstation must be compatible with the existing Computervision Designer V CGP-200X processor and capable of utilizing CADDS 4X rev 4.0 or later software.

7. No additional software support is required at this time. Maintenance support for the hardware in this acquisition will be added to the existing CAEDOS Contract Administered through China Lake.

8. The cost of site preparation is estimated at approximately $14,000.00.

9. N/A

10. The estimated date of delivery is 1 September 1986.

11. No hardware will be released as a result of this acquisition.

12. Method of acquisition will be sole source selection of vendor currently on GSA Schedule.

FSC Group 70 - Part 1 - Section A
FSC Class 7025 - ADP Input/Output and Storage Device
Contract: GS00K86AGS5737
Period of Contract: 23 December 85 thru 30 September 86
Vendor: Finalco Incorporated (Phone #(800)346-2526)
8200 Greensboro Drive
Post Office Box 3606
McLean, Virginia 22103

13. No classified information will be generated from this equipment. This equipment will be located in a secured area.

NAVY PUBLIC WORKS CENTER
ENGINEERING AND PLANNING DIVISION
GREAT LAKES, ILL 60088

Work Req.No.	FY	Description	CWE	CADD Time	Sheets	NACFAC Est (1)	Hourly Savings
A11166	86	INST SAN. SEWER LIFT	30,000	14.7	1	35.0	20.3
A11211	86	INST CAPACITR BANKS	200,000	21.1	1	35.0	13.9
A11289	86	UPGRADE METER'G POLES	20,000	23.4	2	70.0	46.6
A11331	86	RENOV. HIGH VOLTAGE	20,000	30.8	1	35.0	4.2
A11524	86	INST. INTERCOM & UPS	5,000	27.1	1	35.0	7.9
A11890	86	UPGRADE SUSTAT'N M8	120,000	23.9	1	35.0	11.1
A12933	86	CUSTOD'L CONTRCT NTC		20.1	6	210.0	189.9
A20377	86	INSTALL TRANSFER SW	25,000	16.0	1	35.0	19.0
A22373	86	UPGRADE ELECT SYSTEMS	25,000	23.1	2	70.0	46.9
A23151	86	INSTALL CLASSROOMS	30,000	10.1	1	35.0	24.9
A31092	86	INST. X-RAY MACHINE	50,000	11.4	1	35.0	23.6
A31102	86	INST SECURITY LIGHTG	7,500	33.2	3	105.0	71.8
A31103	86	INST SECURITY ALARM	10,000	36.0	2	70.0	34.0
A31123	85	INSTALL FIRE ALARM	20,000	40.1	4	140.0	99.9
A31125	85	INST EMERG. LIGHT'G	15,000	31.8	4	140.0	108.2
A36201	86	INSTALL HVAC		48.2	2	70.0	21.8
A71382	85	RENOV HOUSG PROT-TYP		24.5	4	140.0	115.5
A79510	86	PAINT'G CONTRACT NTC		17.1	1	35.0	17.9
Number of Records: 18		TOTALS:	577,500	452.6	38	1,330.0	887.4

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